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Faculty of Landscape Architecture, Horticulture
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Farmers' perceptions on the effectiveness of push pull technology to control maize stem borer (*Chilo Partellus*) in Gatsibo District of Rwanda.

Marthe Nezehose

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Titel på Svenska: Jordbrukarnas uppfattningar om effektiviteten hos push pull-teknik för att kontrollera majsstamborare (*Chilo Partellus*) i Gatsibo distriktet Rwanda.

Marthe Nezehose

Supervisor: Marco Tasin, SLU, Department of Plant Protection Biology

Co-supervisor: Anna Hofny-Collins, Guest Lecturer at SLU Alnarp

Examiner: Teun Dekker, SLU, Department of Plant Protection Biology

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SLU, Swedish University of Agricultural Sciences
Faculty of Landscape Architecture, Horticulture and Crop Production Science
Department of Biosystems and Technology

Abstract

This case study investigated the perceptions of farmers and the historical effectiveness of push-pull technology to control the maize stem borer *(Chilo Partellus)* in Nyagihanga sector of Gatsibo District (Rwanda). The investigation was done in collaboration with Food for the Hungry/Rwanda, an organization operating in the mentioned region. Historical data from the region show that the push pull technology can significantly increase maize yield while decreasing damages by the maize stem borer. The agronomist and livelihood officer at Food for the Hungry/Rwanda and 27 farmers participated in the study. Semi-structured interviews were conducted in February 2019. The material was analyzed using a framework (thematic) analysis of farmers ‘narratives about the push pull technology. Maize harvest during three consecutive growing seasons (2016A, 2017A and 2018A) showed a remarkable and continuous increase of yield in push pull plots, in comparison with a maize monoculture. Farmers appreciated the technology, mentioning a range of benefits during the interviews but they stressed the challenging side of it. The most-mentioned benefits of the method were stem borer control, maize yield increase and fodder for animals. On the other hand, the most-mentioned limitations were the increase of labor cost (for the very first installation), the necessity of a new crop rotation and the difficulty to access high quality desmodium seeds. The results of the study show that push pull technology is beneficial, as many other previous researchers have proven, especially for maize stem borer control. Nevertheless, the working environment, consisting of the agriculture policy and regulations, the food needs and the income state of smallholders, and many other external factors can have a detrimental impact on it as a farming system. Because the current agricultural policy is not actively supporting the adoption of the push pull technology, the development of a strong collaboration between all the stakeholders is essential to establish a strong maize production system.

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Above all, I thank the Almighty God for the gift of Life and all the good things that happen to me. I would then like to thank my thesis advisor Marco Tasin of the Department of Plant Protection Biology at the Swedish University of Agricultural Science. His office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this study to be my own work, but guided me in the right the direction whenever he thought I needed it. I thank Anna Hofny-Collins my co-supervisor for her expertise about the frame of my thesis, her sense of ensuring that I understood the provided advice, which helped me to make this achievement happen.

I would also like to thank Food for the Hungry/Rwanda staff members who were involved in my study process especially Roger Zürcher (Food for the Hungry/Suisse), Alice Kamau (Country Director/Food for the Hungry/Rwanda), Eric Muhirwa (Cluster Coordinator at Nyagihanga), Jean Claude Hakizimana (Agronomist & Livelihoods Officer at Nyagihanga site) and all the farmers who participated in my study. Without their passionate participation and inputs, the field study could not have been successfully conducted. Finally, I must express my very profound gratitude to my in-law-family members for being in my place and taking care of my children during my years of studies. This accomplishment would not have been possible without them.

Marthe Nezehose

Foreword

During my previous studies (Soil and Environmental Management), I realized that different agriculture practices make a great contribution to the environmental pollution which in turn affects human health. Apart from the environment harm, I have come to realize that we are also facing sustainability problems in food production and agricultural production systems in general. When I finished my Bachelor program, I moved to the rural community in East of Rwanda. There, I worked for Caritas organization in the Support Project for Sustainable Agricultural Systems and Nutrition. While working at Caritas, I was given the opportunity to participate in a one week-training on agroecology and sustainability. It was displayed in 2015 by Food for the Hungry organization which operates in different African countries. After that time, I have discovered a new perspective from which to look at agriculture. In collaboration with, Caritas gave me. I was lucky to meet farmers from different countries and hear about their success stories. The people who held the training inspired my thinking, and I decided to find a way to know more about agroecology. I started learning English and searching for available scholarships in different countries; on the 10^{th} of April 2017, I was offered a scholarship by the Swedish Institute at SLU in the Agroecology Master Programme. Most of the knowledge I obtained during my previous studies was about techniques to increase food production, especially in a small country like Rwanda with more than 12 million of people and a population density of about 450 inhabitants/sq km. I wanted to know how agriculture can be economically profitable while relying on natural processes. During my study period at SLU, I have learnt that agriculture is not just a separate discipline with specific theories and principles to produce food. Rather, it is a complex combination of science and practices which can impact positively or negatively on people's lives. Therefore, in this program I have learnt to compare the environmental costs of food production and food distribution with farm profitability; I have also reflected on the impact that the farming practices we use today have on future generations. The agroecology program has helped me to understand agriculture as a human activity. I have learnt that there are many dimensions to sustainable agriculture production systems, rather than enhancing external inputs use with the intention of increasing agriculture productivity. I have understood that scientists and researchers may explore and apply a holistic view of natural ecological interactions occurring in agro-ecosystems. Agroecology enhances the protection of biodiversity; it helps to maintain the populations of the natural enemies of pests and many other ecosystem services from the environment. Incorporating farmers' knowledge and scientific knowledge is also another aspect that has been emphasized in the agroecology master program and it can lead to the development of sustainable food systems.

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List of Acronyms

CAVM: College of Agriculture and Veterinary Medicine CIP: Crop Intensification Program

GDP: Gross Domestic Product

ICIPE: International Centre for Insect Physiology and Ecology KARI: Kenyan Agriculture Research Institute

MINAGRI: Ministry of Agriculture

NARO: National Agriculture Research Organization RAB: Rwanda Agriculture Board

SOM: Soil Organic Matter

1. Introduction

1.1. General information and farming system complexity

Rwanda is a landlocked country in the East African region with a mountainous landscape that has been exposed to severe land degradation over time. The population size in the country is approximately 12,208,407 and the surface area is 26,338 sq km (National Institute of Statistics of Rwanda, 2017). In 2017, the population density was estimated to be 494.869 inhabitants/sq km. It is the most densely populated country in sub-Saharan Africa. Rwanda has the youngest population in the region: the median age of the Rwandan population is 19 years (18.3 years for males & 19.8 years for females) and the average family size is about six persons (National Institute of Statistics of Rwanda, 2015). Rwanda is divided into 30 districts and four provinces and Kigali City. This study was conducted in the Eastern province, more precisely in Gatsibo District. Rwanda depends on rain-fed agriculture, it has a temperate climate and the majority of the population relies on subsistence farming system. Agriculture is therefore the primary income stream for more than 80% of the Rwandan population (Bizimana *et al.*, 2004). About 30 % of the national GDP comes from the agriculture production of different types of crops, with tea and coffee as the main national exports (Rwanda Economy Profile, 2018).

Farming activities and husbandry (livestock keeping) complement each other; the prevailing livestock production system in Rwanda is a smallholder crop-livestock mixed farming system with an average land-holding of about 0.76 ha (Mutimura *et al.*, 2010). Domestic animals are divided into cattle and others such as pigs, goats, chicken and rabbits. On average, one smallholder family owns one to three cows. Karenzi *et al.* (2013) argued that livestock has an important role in smallholder livelihoods and contributes about 8.8% to the national GDP. The main crops grown in Gatsibo District are maize *(Zea mays)* (49.2%), beans (*Phaseolus vulgaris)* (28.3%), rice *(Oryza sativa)* (2.2%), standing crops like banana, and root crops such as Irish & sweet potatoes; fruits and vegetables are grown in relatively small quantities (World Bank Group, 2018).

Maize was chosen as a priority crop in the study region according to the Land use consolidation program which was introduced in 2008. The program aimed at getting control of land fragmentation problems by increasing the agricultural yields and motivating the market-oriented and competitive agriculture production (MINAGRI, 2019 in Nilsson, 2018). The early implementation stage of the program has been difficult as farmers wanted to stick to other crops than maize. This caused conflicts between farmers and local leaders who were supervising the implementation process. Some farmers adapted progressively to the program and others grew maize to respect regulations rather than out of personal conviction.

Any change or adaptation to a new practice in agriculture requires a close collaboration and understanding between all the stakeholders involved in the sector (Francis *et al.*, 2013). Vandermeer (2011) discussed differences between approaches used by agronomists and agroecologists; whilst both seek to understand problems within ecosystems, their way of handling the existing problems differs (Vandermeer, 2011). Agronomists act as problem solvers; on the other hand, agroecologists want to make farms free of problems, they focus on prevention and they seek balance, between ecosystem components. In contrast, farmers have strong attachment to traditions such as food preferences and crops to grow amongst other things. This applies to the agriculture context in Rwanda.

This study was concerned with maize production as one sector that has been subjected to the land use consolidation reform. Though maize was an important crop in Rwanda, it was not considered as the main food crop, and was not grown to such a large extent as sorghum. The agriculture policy then promoted the value chain of the maize crop as well as its production scale. Agriculture institutions ensured the availability of hybrid varieties of maize and other agriculture inputs; farmers were given the inputs as agricultural credits at the beginning of the growing season, and they had to pay after the harvest. The promotion was implemented throughout the CIP which resulted in a considerable increase of maize production (Claver, 2011). Farmers enjoyed an increase of maize during the early years following the implementation of the CIP, especially in 2009 where the relative increase was about 36.25% (MINAGRI, 2011). After this period, the maize yield started to decrease gradually and farmers faced a number of problems related to pest resistance and non-adaptation of improved varieties of maize as farmers had to be given new seeds every growing season. According to the National Institute of Statistics of Rwanda (2019), the latest average yield of maize in 2019A was estimated to be 1.6t/ha which is relatively low.

A number of factors such as the continuous use of synthetic fertilizers, pesticides, overexploitation of the farms, high cost of improved seeds, and the late delivering of seeds and fertilizers can explain the observed yield decrease. The synthetic fertilizers create changes in all three soil compounds which are soil structure, nutrient flows and the soil biota (Vandermeer, 1995). These changes result in short term improvements but they may cause long term negative effects such as the yield decrease in this situation. Vandermeer (1995) also mentioned that the frequent chemical control of pests may reduce the community of natural enemies and develop into pest resistance to the insecticides which is another possible cause of yield decrease. Hence, the adoption of biological control can provide effective result favoring the development of natural enemies ‘populations (Vandermeer, 1995).

In the case of this study, the imported maize seed varieties were not fully adapted to local conditions, as opposed to land races that were there before CIP. Therefore they have been susceptible to pests and diseases after a short period of remarkable yield performance. The introduction of land use consolidation policy resulted in less food diversity and high prices of different food items. According to the World Bank Report (2018), more than 38% of children less than five years of age in Rwanda suffer from stunting and malnutrition problems; and the main cause is the lack of potential resources to satisfy food needs at the household level. Reduced soil fertility, pests, and climatic disturbances such as heavy rains and drought are the main constraints for maize production as well as the agriculture sector in general. Rwanda's agriculture policy tries to promote the use of external inputs as a strategic way to cope with all these problems and produce high quantities of food items. However, external inputs (pesticides, inorganic fertilizers and others) are expensive compared to the limited income sources of farmers. Improving soil fertility and crop protection are important issues to discuss in order to improve the agricultural production system and thus enhance food security in Rwanda. Though there existed different disease and pest problems in maize, after 2009, maize production was predominantly invaded by stem borer (*Chilo Partellus)* that touched all corners of the country especially in 2013 and early 2014. The use of pesticides did not help to cope with the problem. MINAGRI reported the national maize yield loss of about to 10 000 tones in the end of 2013 beginning of 2014 (which means the growing season 2013A). In the wake of this, it was crucial to find an alternative solution. RAB started working together with ICIPE, and the Food for the Hungry/Rwanda organization to introduce the push pull technology to control stem borer moths in maize fields. Since then, ICIPE has established field experiments in Bugesera District, and Food for the Hungry/Rwanda assists 110 farmers in how to use the push pull technology in Gatsibo District, Nyagihanga sector.

The adoption of the push pull technology during the last two to three years of intervention has already shown progress in reducing the maize stem borer effect and increasing yields. On the other hand, the approach may encounter factors related to specific needs of smallholder farmers and local agriculture policy. The land scarcity due to population density can be one of the limitations as farmers need a more diverse and quick production for food consumption than perennial forages intercropped with maize (Isaac Mbeche Nyang'au, 2018). In addition to that, all researches conducted so far have not shown how crop rotation can be managed and for how long push pull technology will last in the same field before the system requires renewal. Therefore, this study is designed to reveal farmers' opinions about benefits and challenges of the push pull technology. This can help all stakeholders engaged in maize production to design a suitable way forward and make the practice more effective and achievable.

This study is beneficial and important to the community involved in maize production in Rwanda in general. The Food for the Hungry/Rwanda will benefit from this study as a self-evaluation of their on-going activities in improving food security and farmers' livelihoods. The study itself is a learning process, the student will experience farmers' knowledge and their perceptions of the adoption of sustainable practices such as push pull technology and the driving force behind their decision making process. To facilitate the expansion of the push pull technology, it is necessary to know the benefits and limitations of this farming practice in this specific context.

1.2. The theoretical framework

Intercropping is a traditional practice which consists of growing more than one species in the same field regardless the sowing and harvesting time because they are not always the same (Hauggaard-Nielsen *et al.*, 2005). Intercropping is mostly used in low-input cropping systems in tropical regions (Bedoussac *et al.*, 2015). Its purpose is the management of complex interactions between companion plants in order to maximize yield as well as the individual performance in terms of growth, productivity and crop protection (Mousavi & Eskandari, 2011). The intercropping systems also can be designed for nutritional diversification. Moreover, intercropping explores the crop complementarity leading to total high yield and net return (Kheroar & Patra, 2013). The ecological interactions in cereal-legume cropping systems emerge in the fulfillment of different objectives and benefits like (1) nitrogen fixation, (2) animal feed, (3) ecosystem services, (4) climate mitigation, and ultimately (5) resilience of the cropping system (IAASTD 2009 in Bedoussac *et al*., 2016). The push pull system is one example of grain-legume cropping systems, where there is a wide complexity of benefits leading to food security and smallholder livelihoods improvement. Nicholas *et al.* (2018) have developed a theoretical framework for assessing farmers' interests in using push pull technology to control maize stem borer moths and how it relates to food security, nutrition and farmers' livelihood improvement. This framework which has been used in Western Kenya was adapted to the Rwandan context where farmers grow maize and have adopted push pull technology with the assistance from Food for the Hungry/Rwanda.

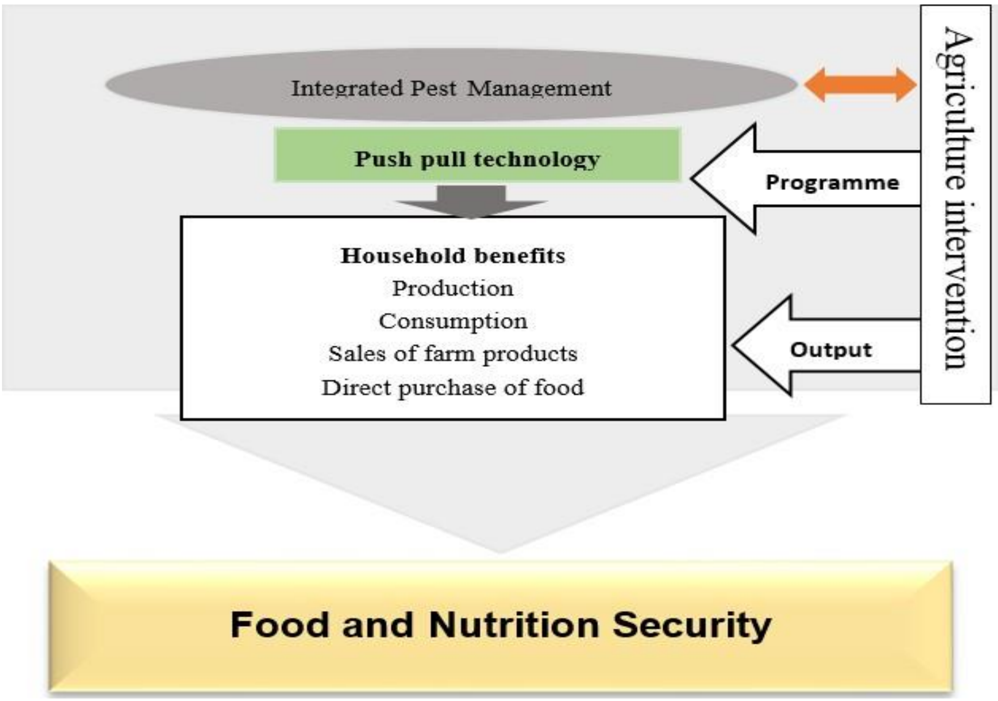

Figure 1: The theoretical framework of push pull and how it relates to food security and nutrition (adapted from *Nicholas et al*., 2018).

1.3. Aim and research questions

This study aims at exploring farmers' perceptions about the push pull technology and its effectiveness to control maize stem borer. The main focus is in relation to benefits, limitations and future perspectives of the technology. The student will learn more about the technology and how it contributed to reducing the effect of the maize stem borer among households assisted by Food for the Hungry in Rwanda, Gatsibo District. The research question that needs to be answered by this study is, "What is the current efficiency and future perspective of push pull technology in controlling maize stem borer in Rwanda?"

Three guiding objectives related to this research question are listed as follows:

- Evaluate the efficacy of push pull technology for maize stem borer control.
- Investigate the benefits, limitations and future prospects of push pull technology.

1.4. The push pull technology

Mixed cropping systems are beneficial because of ecological interactions existing between different types of crops grown simultaneously in the agroecosystem (Gliessman, 2015). In mixed cropping systems, weeds and cover crops may have either a detrimental effect through competition or a beneficial influence to the crop through mutual complementarity and facilitation (Kaci *et al.,* 2018). On the other hand, mixed cropping systems enhance the rational use of natural resources and the diminution of the reliance on external inputs and their impacts in the natural environment. These systems bring in knowledge-intensive processes that require optimal management of nature's ecological functions and biodiversity to enhance agricultural system resilience, efficiency and farmers' livelihoods (Tittonel, 2014). The push pull technology is a practical example of such complex interactions. Maize is intercropped with desmodium grass and surrounded by Napier grass (*Pennisetum purpureum*) or brachiaria (*Brachiaria brizantha)* grasses on the plot edges. There exist many different varieties of desmodium and each of them has a specific scientific name. The two common varieties in push pull technology are the green leaf desmodium (*Desmodium Intortuum*) and silver leaf desmodium *(Desmodium uncinatum).*

Push pull technology was set-up as a reliable integrated pest management strategy by the ICIPE in Kenya around 1987 (Midega *et al.,* 2015). Ecological interactions exist between all three types of crops to stabilize the system against maize stem borer and the purple witch weed *(Striga Hermonthica)*. The infestation by maize stem borer moths triggers the release of volatile chemicals by desmodium which repel the stem borer moths and prevent them from damaging maize plants (Khan, 2008). After the repellent action, the trap crop (Napier grass or brachiaria) releases another type of volatile chemicals at the beginning of the period of oviposition by maize stem borer (Cook, 2007). Those chemicals prevent eggs from developing as they are trapped into a fluid and sticky substance on the leaf surface of the Napier grass or brachiaria on the plot contour (Hassanali *et al.,* 2008).

Besides their role of controlling maize stem borer, desmodium and Napier grass are considered as inputs (Pickett *et al.,* 2014). The two plants serve as fodder for animals. Desmodium is a nitrogen fixing legume. It adds approximately 110 kg N/ha/year into the soil. That amount of nitrogen corresponds to nearly 160 kg N/ha/year of nitrogen fertilizer (Pickett *et al.,* 2014). Therefore, the push pull technology improves soil fertility and avoids the side-effects of chemical fertilization. The nitrogen fixation in the soil boosts the abundance of shoot and root biomass, meaning an increase of SOM as well (Narwal, 1998). At the root system level, desmodium releases allelochemicals that inhibit the attachment of striga parasitic weed on maize. Hence, push pull technology is a complexity of ecological interactions that are beneficial for the entire system stability. The plant-plant interactions and release of chemical compounds in the push pull system happen below and above the ground as shown in Figure 2. Such processes make the push pull technology a multifunctional system sustained by natural diversity (IPES-Food, 2016).

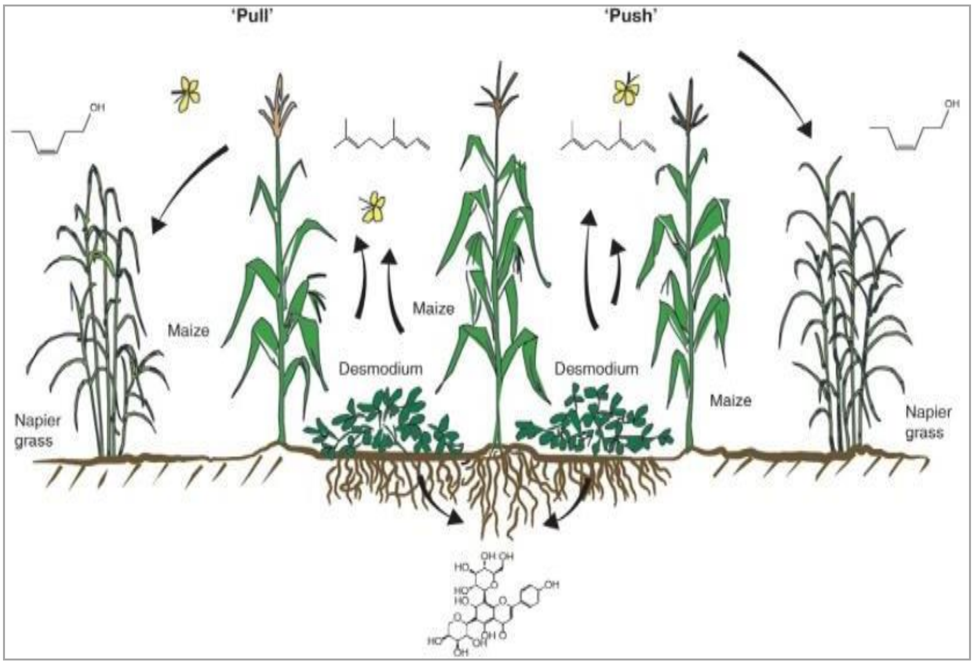

Figure 2: Graphical representation of the push pull technology (adapted from *Pickett et al*., 2014).

Currently, the push pull technology is promoted as a measure for maize stem borer control in sub-Saharan Africa region and thousands of smallholder farmers continue to adopt it (Murage *et al.,* 2012). ICIPE works in partnership with other research centers i.e. NARO in Uganda and more recently RAB in Rwanda. They focus on knowledge sharing throughout trainings for both agriculture advisors and farmers. These centers invest in new research subjects and projects aiming at the expansion of the push pull technology and enhance sustainable maize production. They also focus on the improvement of livelihoods among smallholder farmers. The push pull technology has contributed to maize yields increase and milk production in Kenya where the program started (Cook, 2007). It has shown a positive impact on food security and farmers' livelihoods in general (Fischler, 2011). It has also been recognized as a technology adapted to tropical conditions and climate change as it is based on drought tolerant companion plants (Midega *et al.,* 2018). A study conducted in Bongo and Siaya regions described a significant difference in terms of damage levels caused by maize stem borer (Khan *et al.*, 2018). It was carried out both on maize and sorghum and the data was collected from ten participants' fields. The damage level was relatively high when maize was grown as a sole crop. In contrast, the damage was very low when sorghum and maize were intercropped with desmodium in push pull system. Figure 3 shows historical data from an experiment conducted at Mbita site of the KARI and later spread over 14 districts. The study revealed a significant difference between push pull and monocrop plots in terms of maize yield quantity (Hassanali *et al.,* 2008). The maize yield was higher in push pull plots and it was lower in monocrop plots because of the damage by stem borers.

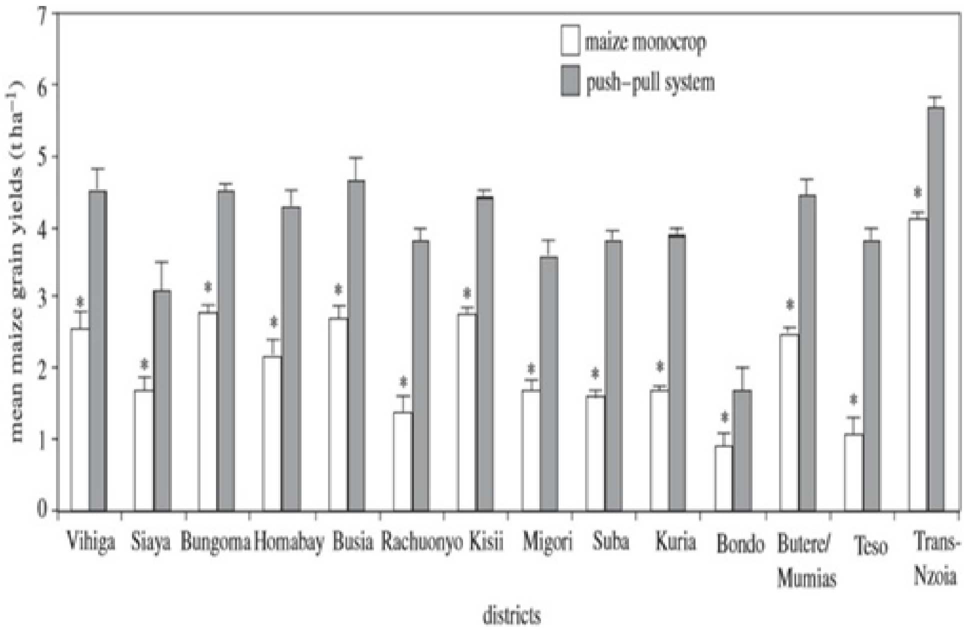

Figure 3: Yield differences in push pull and control plots in 14 districts of Kenya during the 2005 rainy season. Bars with an asterisk are significantly lower ($p<0.05$, t-test) (adapted from *Hassanali et al.*, 2008).

As it was explained in the introductory section, Rwanda experienced maize yield losses caused by maize stem borer. Predominantly, the period of 2013-2014, about 21 districts all around the country where maize is the primary crop have been touched by this pest. Since it was a community preoccupation, MINAGRI delivered pesticides to tackle such an emergent issue and people at different levels helped in the spraying. The next year 2015, in collaboration with MINAGRI, the ICIPE started to operate under the umbrella of RAB to introduce the push pull technology in maize production. The ICIPE placed the first experiments in Nyamata sector of Bugesera District. In addition, ICIPE also collaborated with Food for the Hungry/Rwanda to develop the push pull technology in Gatsibo district as this organization was engaged in the region to help in smallholder livelihoods improvement. Food for the Hungry/Rwanda operates specifically in Nyagihanga sector of where most of smallholders grow maize. Both Bugesera and Gatsibo Districts are located in the Eastern province one of the regions that experienced severe damages by maize stem borer.

2. Methods and Materials

2.1 Site description

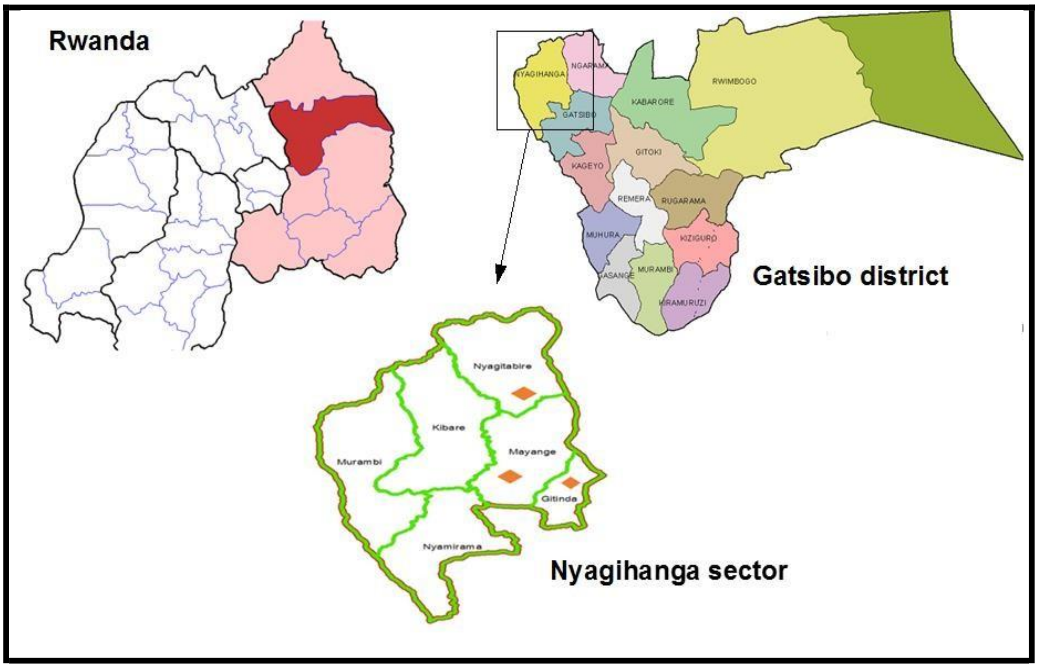

Figure 4: Maps of the study sites (adapted from the unpublished documents of Food for the Hungry, 2019 and www.wikimedia.org/wikipedia/commons/b/bd/GatsiboDist.png).

As detailed in Figure 4, Gatsibo District is located in the Eastern Province of Rwanda (1°36'S 30°27'E). It occupies 1,578 sq km, the total population is estimated to be 433,997 and the population density is about 275 inhabitants/sq km. The district is divided into 14 sectors, 69 cells and 603 villages (World Bank Group, 2018). The study site was precisely Nyagihanga, one of 14 sectors of Gatsibo District. The dominant crops in this region are maize, beans and rice. Other crops like banana and different types of vegetables are grown in small quantities. Nyagihanga sector includes six cells and 55 villages. The participants were taken from three cells: Gitinda, Mayange and Nyagitabire (see appendix 1).

2.2. Sampling strategy and presentation of the participants

The participants in the study were chosen according to the project implementation model Figure 6, starting with a group of ten farmers model farmers who have been trained in the push pull technology as well as other agro-ecological practices disseminated by Food for the Hungry/Rwanda. Every model farmer was responsible for a new group of ten farmers with whom he/she shares his/her experience; the new group members were then known to be disciple farmers. They learn from model farmers and, will share knowledge with others farmers to continue the dissemination of the technology.

A sample of 30 farmers was randomly chosen from the list of the beneficiaries, one group of 15 farmers with push pull technology, and another group of 15 farmers who have been identified to be part of the push pull technology though they do not have push pull plots yet. Unfortunately, three farmers were not able to participate in the interview, so the total number of respondents ended up being 27. Their participation was canceled especially because they were unexpectedly not available at the planned date. They asked for a late participation which was not possible on my side as I was running out of time. The memorandum of understanding I had signed with Food for the Hungry/Rwanda had to be closed by a field report, therefore I had to spend time preparing on that as well. The distribution of participants was determined as follows: 15 farmers with push pull technology divided into six model farmers (1 Gitinda, 2 Mayange, and 3 Nyagitabire) and 9 disciple farmers (3 Gitinda, 4 Mayange, 2 Nyagitabire); the second group of 15 without push pull technology was made up of beneficiaries from agriculture cooperatives and they were mainly from Nyagitabire cell Figure 6. Though they have not used the push pull technology yet, they participated in the training sessions about it. They attended the knowledge sharing during field days for the practical demonstration of the push pull plot. Therefore, they had a certain level of information about the push pull technology.

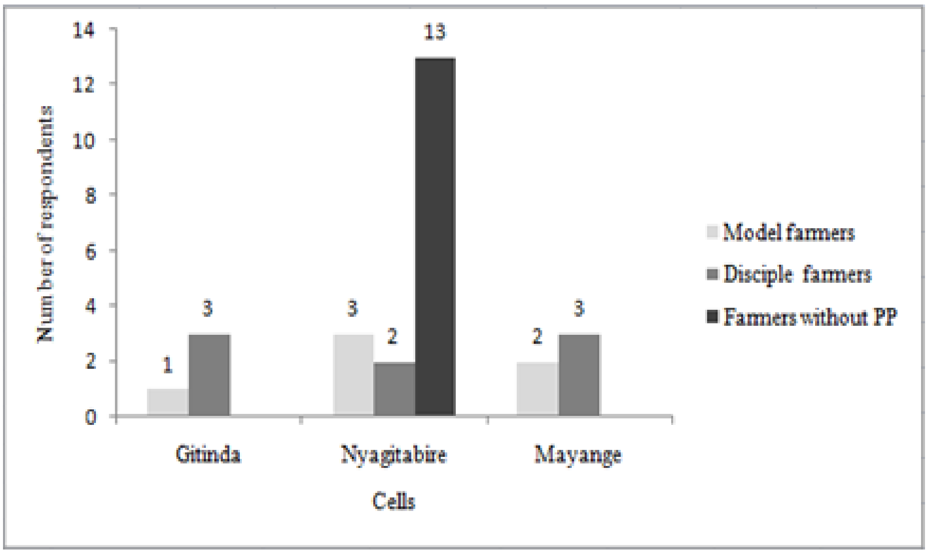

Figure 5: The distribution of the respondents by cells (Author).

2.3. Semi-structured interview

Creswell (2014) explained qualitative method as a procedure of capturing and understanding people’s views towards a human activity. The qualitative method of research involves the raising of questions and collection of data in the participant’s surroundings where data analysis is built from specific to general themes (Creswell, 2014). For this particular study, the qualitative data was related to farmers’ views on the effectiveness of push pull technology.

Based on predefined topics, the data was collected through semi-structured interviews with farmers. The interview guide was around predefined topics in order to easy the information flow.

2.4. Statistical analysis

The quantitative data was collected from published and unpublished documents from different sources. MS Excel and the analysis of variance (ANOVA) have been performed to define the yield differences in push pull system and control plots within different growing seasons.

2.5. Thematic analysis

All 27 interviews were recorded with the exception of two farmers who had doubts about their confidentiality, and were not comfortable with the recordings. Their responses all along the interview were written down by the interviewer. The data analysis was done using the thematic analysis approach, a process of identifying themes within qualitative data (Delahunt & Maguire, 2017). The samples in qualitative research tend to be small in order to support the depth of case-oriented analysis that is fundamental to this type of study (Vasileiou et al., 2018). Braun & Clarke (2006) detailed thematic analysis approach in six different steps that help the researcher to get to the concluding report. The first stage starts with the transcription of recorded interviews; then the researcher familiarizes with the data through repetitive, active reading through the whole data set and focusing on the meaning. The second stage is to generate codes for key and interesting ideas in the data. Thirdly, the researcher looks for themes and sub- themes according to the codes developed in the second stage. The fourth stage of the thematic analysis is reviewing the themes and deciding on those that can be broken into other separate themes or those that can be rejected. The next step of defining and naming remained themes. In the last, the researcher produces the report identifying the essence of every single theme and all themes in general Braun & Clarke (2006).

The different views from all participants together with the data from the published documents and the existing reports in the organization were synthesized to:

- gain an understanding of the performance of the push pull system in the area where Food for the Hungry is operating, and
- build inferences and select suitable recommendations to potential stakeholders for what might be improved to achieve a sustainable and profitable maize production system and choice of practices that can contribute to improve smallholder farmers' livelihoods.

2.6. Ethical considerations and study limitations

Before going to the field, a meeting was held at Food for the Hungry Rwanda's main office in Kigali. The Country Director, Human Resource Manager and Cluster Coordinator in Nyagihanga were present. We discussed about the different subjects to consider while conducting interviews, a Code of Conduct and a Memorandum of Understanding between the two parties. Farmers were asked to choose a suitable day and time for the interview as we had to visit the push pull plot in the case of farmers with push pull technology. The study period was a rainy sowing season, therefore farmers needed to maximize their working hours. Their schedule was sometimes busy; therefore I had to postpone the visit. On my side, primary limitations have been transportation means and the limited time compared I had on the field. Despite those limitations, the study has been an interesting experience with farmers but more could have been done especially to collect different kinds of data regarding farmers' livelihoods in relation with the adoption of push pull technology.

3. Results

3.1. Quantitative results

3.1.1. Maize yield performance in push pull and mono-cropping system.

In order to help farmers to observe the yield differences in both push pull and mono-cropping/control plots, every household had to display two adjacent plots of equal surface: one, for the push pull technology and the second as the control plot where maize was grown as a sole crop. Farmers received and used the same seeds of maize and desmodium from Food for the Hungry/Rwanda. However, they had to find fertilizers themselves. Farmers who owned animals could use animal manure and compost. Others could buy fertilizers depending on the economic situation of their households. Either they bought compost, animal manure, or synthetic fertilizers. In figure 6, the maize yield quantities in push pull plots have been registered during three growing seasons all along three consecutive years. The considered growing seasons were 2016A, 2017A and 2018A. The yield quantities displayed in Figure 6 were provided by the agronomist & livelihoods officer who work closely with farmers.

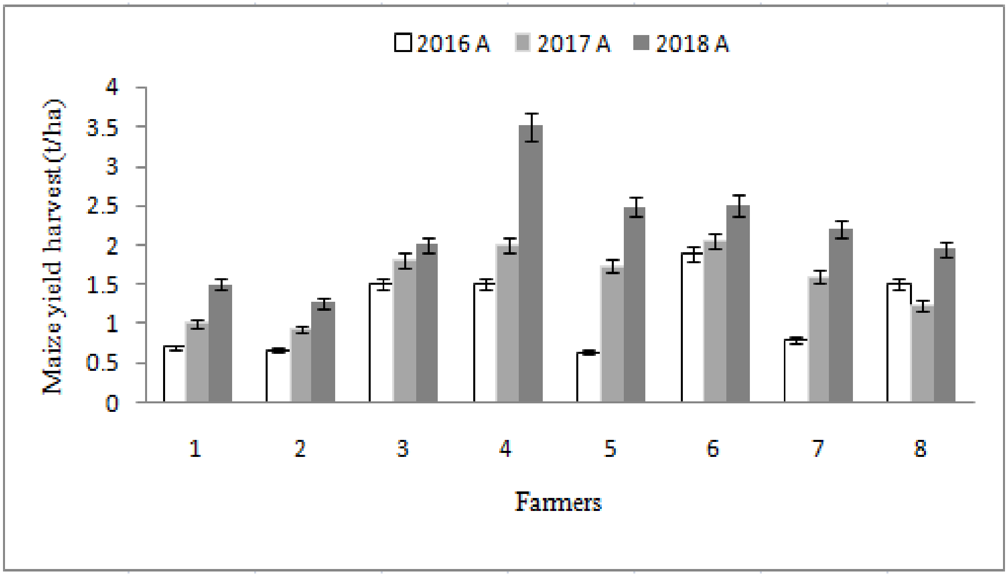

Figure 6: Maize yield performances in eight households with push pull during three different growing seasons. The overall yield increase was significant different ($p<0.05$) (source: Food for the Hungry, 2019)

A sample of eight farmers was considered to observe the yield differences within three different growing seasons. The statistical analysis with MS Excel was based on two main factors which are the agriculture practice (push pull system for this case) and the type of fertilization. The analysis of variance without replication was performed and the results showed a continuous increase of maize yield and a significant difference ($p<0.05$) of maize yield increase along three considered growing seasons. All eight farmers used the push pull system and the same seeds given by the project. Despite small exceptions at the level of farmer 3, farmer 6 and farmer 8, the maize yield difference was significantly different for the next growing season.

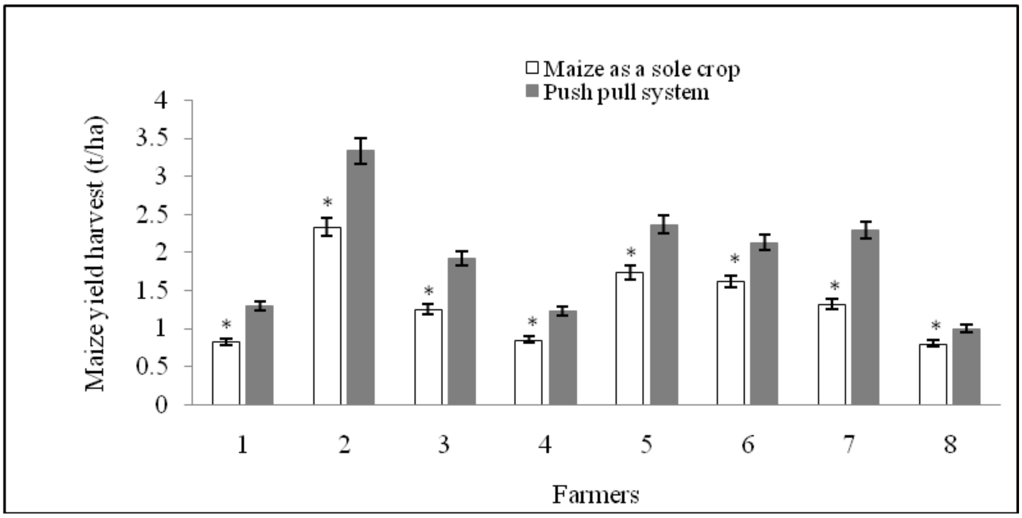

Figure 7: Yield differences in push pull and control plots in eight households during the 2018B growing season. Bars with an asterisk are significantly low ($p<0.05$) (secondary data from Food for the Hungry, 2019).

In figure 7, there is a comparison between maize yield in push pull system and when maize was grown as a sole crop. This comparison was based on the data for the second growing season of the year 2018. The results showed that maize yield in push pull plots was significantly higher ($p<0.05$) from the maize yield harvested in mono-cropping system. For some farmers, the difference was highly considerable, and it was slightly high for others. Such variations might be caused by different factors which will be thought through in the discussion section.

3.1.2. The contribution of push pull technology to the household income

The largest proportion of the household income among smallholders was from farming activities with small contributions from different off-farm works. For 72% of adopters, the main income source was farming activities, 20% combined farming with animals, 4% combined farming with brickwork and 4% with small house rent in the nearest center. The mentioned percentage for farming activities includes the contribution of the push pull technology to the household income. On average, among farmers who adopted the push pull technology, 40% of the maize harvest was designated for household consumption, while the majority (60%) was for sale at the market. The proportion of maize sold increased with the push pull technology adoption and therefore the contribution to the household income increased as well. However, at the market time the separation between the maize produced in the push pull plot and that in the control plot was not easy. The harvest from the push pull plot was primarily kept as seeds for the next growing season and the remaining amount of maize was mixed up either for the household consumption, labor payment or the market. Farmers raised concerns about the low price for maize and the impact on their household income. Nonetheless, the push pull technology also enhanced the household income, not only because of the higher yield, but also because farmers could save the amount of money previously used to purchase inputs particularly inorganic fertilizers. All participants with push pull technology were able to reduce the inorganic fertilizers by 50% compared when they grew maize as a sole crop and depending on the type and the cost of fertilizers was between 400 Rwf/kg and 600 Rwf/kg. The majority of participants argued that the direct contribution of push pull technology to the household income was related to less application of inorganic fertilizers and fodder production. Farmers mentioned that the increase of maize yield due to the use of push pull technology would boost the household income but the prices of maize harvest contrast to the proportional increase of household income. At the harvest time, the selling price of maize is between 80 Rwf/kg and 100 Rwf/kg which is relatively low compared to the buying price of 300 Rwf/kg and more few months after the harvesting period.

3.2. Qualitative results

3.2.1. Source of agriculture information in the study area.

The majority of the respondents (adopters and non-adopters) had received agricultural information from different sources rather than the implementing project (Table 1). Unsurprisingly, because of the research set-up in collaboration with Food for the Hungry/Rwanda, 100% of respondents had received information and advice from the project advisor. A closer observation of the results revealed that training program was an important source of agriculture information (about 66%) for farmers. The sector agronomist was another important source of agriculture information covering 53%. As a governmental delegate, the agronomist is the key player for the implementation of contemporary agriculture reforms and policies within the region. Farmers also admitted to take advice and information from grandparents and elders. This type of heritage source of traditional knowledge was received by 52% of respondents. Due to the group membership approach, the agriculture information from neighboring farmers was also very important in the community. 48% of the respondents confirmed to receive agriculture information from neighboring farmers especially model farmers. Lastly, 26% confirmed to take the agriculture information from the radio programme related to agriculture.

Table 1: Source of agricultural information in the study area.

	Gitinda (n=4)	Nyagitabire (n=15)	Mayange (n=6)	Pooled (n=27)
Agronomist & livelihoods officer/Food for the Hungry/ Rwanda	100	100	100	100
Sector agronomist	25	40	33	53
Trainings & Workshops	75	80	50	66
Grandparents	60	40	83	52
Radio	50	26	50	26
Other farmers	0	60	33	48

3.2.2. Benefits of push pull technology

By the use of thematic analysis, the information gained from the semi-structured interviews was categorized into benefits and limitations of the push pull technology as expressed by adopters and non-adopters alike. The benefits and challenges highlighted in the next section, are the emerging themes resulting from the six steps of the thematic analysis as described in section 2.4.

Yield increase

All 14 respondents-adopters of the push pull technology stated that they realized a maize yield increase in their respective plots. On the one hand, the maize yield difference was observed between the push pull technology and control plots. On the other hand, the yield difference was also noticeable within push pull plots from one growing season to the next (Figure. 6). The agronomist and livelihoods officer at Food for the Hungry/Rwanda helped farmers to keep their yield records using paper cards; and, they were encouraged to practice the record keeping in their regular farming activities. Thereafter, they can compute the production costs, compare with the output value and make relevant decisions. Model farmers tried to keep the records more than did the disciple farmers. They need regular follow up and time to familiarize with the exercise. From the observations, the respondents (adopters and non-adopters) related the yield increase to the efficacy of the push pull technology to control maize stem borer. Next is the example of statements from one farmer with push pull technology and one other farmer without push pull technology yet.

"*I used the same amount of fertilizers in these two plots, the yield in push pull is higher because stem borer moths did not damage my maize plants* (Farmer 13).

"I do not have the push pull technology yet, but I have learnt so much about it during the training sessions. Some of my group members installed the push pull technology in their farms. My neighbor used to produce 40 kg of maize in his small plot, but last time he harvested about 70 kg because there was no damages caused by stem borers" (Farmer 16).

Fodder for animals

The push pull technology consists of the association of desmodium grass intercropped between rows of maize and Napier grass or brachiaria on the contour of the plot. Napier grass and brachiaria are used as fodder for animals. Instead of these two type of grass, the majority of adopters used Napier grass as it is locally available and has been grown as a fodder since many years in the region. The main reason of using Napier grass, has been that Food for the Hungry/Rwanda difficulties to find seeds of brachiaria. Though these seeds were available a bit late, they were given to some farmers. The narratives from who have push pull plots emphasized fodder production as another important benefit of the push pull technology. Among others, these two examples explain how farmers perceived push pull technology regarding fodder production for animals: the first farmer underlined the multi-functionality of desmodium fodder. According to him, with push pull farmers can harvest maize yield and fodder for animals such as cows, chickens and rabbits. Another farmer shared his experience about a milk production increase due to the adoption of push pull technology. This farmer also noticed that brachiaria can be resistant to disease compared to Napier grass which was affected by a yellowish disease. Therefore, the expansion of push pull technology can help farmers to find the alternative feed for animals in the case where brachiaria is used as a trap crop.

Soil fertility improvement

The use of cover crops such as desmodium improves the physical, chemical and biological properties of soils (FAO, 2011). Cover crops can be grown independently or intercropped with food crops as in the push pull technology where desmodium is intercropped with maize. According to FAO (2011), desmodium plays an important role in the push pull mixed cropping system like nitrogen fixation, preventing soil leaching, facilitating SOM accumulation and improving the overall soil fertility. All these processes taken together, in addition to the stem borer control, result in synergies and regulation between components of the agroecosystem (Altieri & Nicholls, 2003). All participants (adopters and non-adopters) mentioned soil fertility improvement among many other benefits of the push pull technology. First, they have been taught during the training sessions. Second, they have learnt with the adoption of the push pull technology and through observation. For example, farmer 13 confirmed that she just cuts down desmodium and live it in her plot as mulch to keep the soil cover and the SOM as the mulch decomposes gradually. Another farmer (farmer 2) shared her experience and appreciation of desmodium plant as a fertilizing plant even before the intervention of Food for the Hungry/Rwanda in Gatsibo District.

"I have known desmodium grass from the past years before 1994 when it was distributed to coffee producers. It was given as a fertilizing grass, mulch for coffee farmers and also a fodder for animals. When I saw it in maize of my neighbor, I was surprised. I asked him, and he explained about the push pull technology; since then, I joined his group" (*Farmer 2).*

3.2.3. Challenges of push pull technology

Labor cost and time consuming

All three companion plants in the push pull system are intercropped according to a specific design with regards to spacing precision in order to enhance resource utilization (Zhang & Li, 2003). Therefore, respecting the precise measurements requires additional time and labor. Among participants, 85% of farmers with confirmed that the first installation of the push pull plot was labor intensive and time consuming. According to them, the cutback of desmodium can also require special attention and time investment regarding the cutting periods and frequencies of desmodium intercropped with maize. In general, smallholder farmers depend predominantly on family labor (FAO, 2015). Though some of the participants could hire part time workers when needed, the majority had to rely on family labor. In addition, push pull technology was introduced in a diverse and existing farming system. Farmers used to grow other crops which contributed significantly to the household income; consequently they were conscious about the time allocation. On the other hand, whilst they stressed about labor investment during the first installation of the push pull plots, they admitted to be aware of the future reduced labor cost once the system became established as desmodium and Napier grass are perennials. In the beginning, the push pull plot installation was done as a group activity for demonstration at the household level and the labor was shared among participants on the field day.

Quality and quantity of seeds

The implementing project model was designed to empower farmers in different ways. All the seeds (desmodium and brachiaria) were freely given by the project to farmers. After the sowing time and germination, desmodium were found in two different varieties: the green leaf desmodium and silver leaf desmodium. About 23% of the adopters turned out to be given the silver leaf variety and 77% received the green leaf variety with mixed small amounts of the silver leaf variety. Furthermore, the brachiaria seeds were not available at the same time as desmodium. Consequently, not all farmers with push pull system had the same contouring neither grass, nor the same desmodium variety intercropped with maize. It was observed that the green leaf desmodium variety had a low germination rate and the project had to redistribute new desmodium seeds. This was because there was no clear desmodium to cut down as a perennial plant very crucial in maize stem borer control process. Figure 9 shows in the left picture with green leaf desmodium variety, a nearly bared soil and stunted desmodium stems, and in the right picture the silver leaf desmodium variety with relatively high biomass which covers the soil.

Figure 8: Germination difference between the green leaf and silver leaf desmodium varieties (Author).

Need for diversification and economic benefit

According to Nicholas *et al.* (2018), in Kenya the push pull technology contributes to food and nutrition security for smallholder farmers. The average farm size for farmers with push pull technology in this study was approximately1.8 ha. This number is higher than the national average of 0.76 ha. The reason for this is that among them were two farmers with relatively large farms of 6 ha and 7.5 ha, which affected the mean. The average size of the push pull plot is 0.6 ha regardless of farm size per household. Consequently, the contribution of maize yield to the household income is relatively small. Firstly, because the quantity produced on such small plots is low, secondly because the price of maize is very low at the market. More than 40% of the maize they produced was assigned to household consumption. Farmers with a limited source of income are obliged to purchase food items not produced at the household level, and/or to pay for other household expenses such as school fees, clothing and health insurance. Farmer 13 argued that maize production provides a low economic compared to other food crops and the expansion of push pull technology may be problematic as the intercropped grasses are perennials. She was quoted: *"I have told this to our facilitator, in a plot of the same size I can gain an economic benefit of 50 000 Rwf when I grow maize compared to 200 000 Rwf if I replace maize by potatoes, there is a big difference. I will just keep the push pull plot of 0.01 ha for maize, because I need other types of food crops as well as the economic benefit to satisfy household needs".*

Crop rotation

The information regarding crop rotation in push pull system was displayed differently by the respondents during the interviews. 7% of the respondents said that they can grow another crop in the push pull plot after five years of maize growing. About 93% said that they did not know something about crop rotation within push pull technology. During the last three years of intervention, all farmers with push pull technology grew maize consecutively. For some, the only thing was to move the technology to another plot but the rotation of crops within an established push pull plot was not observed. One model farmer shared his doubtful thinking about crop rotation in the push pull mixed cropping system. He wondered what other types of crops that can be grown in the push pull system, other than cereals.

In order to have clear explanations, the question about crop rotation within push pull system, the question was also asked on the project level. The agronomist and livelihoods officer also confirmed that they do not have yet the package about crop rotation within push pull. He argued that the project would appreciate different agriculture institutions such RAB, CAVM to explore different topics about push pull system including crop rotation. According to the agronomist, though their intervention was a continuous learning process, it is hard to conduct research while working with farmers. The main focus of the project is generally built on the pre-determined logical framework; therefore the intervention form the scientific groups with budgets allocated for research would be good to find ways to sustain the push pull system as well as all other activities provided by Food for the Hungry or any other NGOs operating in Rwanda.

4. Discussions

4.1. Quantitative data

Khan *et al.* (2011) explained the push pull technology as a mixed cropping system for integrated pest management leading to continuous yield increase all along respective growing seasons. This is in line with different research findings. For example, Midega *et al.* (2015, p. 73) pointed out that field studies conducted in Western Kenya denoted that the use of push pull technology in maize production caused a significant reduction of over 80% in stem borer infestation. Several studies also in the East African region confirmed the reliability of push pull technology to improve the soil fertility in general. For instance, Khan *et al.* (2011) discussed how push pull technology increased the SOM, soil moisture content and other attributes important to soil fertility improvement. The results of this study in Gatsibo District/Rwanda were in line with all the previous research findings. The implementation of push pull technology in the region was not designed for research purposes, and the on-farm record keeping was designed to be appropriate for farmers to use rather than to generate scientifically accurate data. Therefore, the possibility to compare yields in push pull technology and mono-cropping plots of maize was good enough for farmers to appreciate the effectiveness of push pull technology.

The general observation showed the importance of push pull technology in reducing the stem borer effect as well as the maize yield increase. However, quantitative data regarding as displayed by the project facilitator, may encounter different sources of variations in maize yield harvests depending on the individual farm management of farmers. As mentioned previously, farmers received seeds from the project; they had to find fertilizers themselves. However, the economic situation of farmers, the choice of fertilizers, the dosage and others possible factors can be source of variations observed on figure 7 and figure 8; for some farmers, the yield increase was considerably higher while it was medium for others. Secondly, the consideration of different growing seasons was hard to explain. For this, the records only showed maize yields in push pull plots for 2016A, 2017A and 2018A while data for both push pull and control plots was for the second season of the year 2018 (2018 B). Moreover, the data may still be valid because this study was not based on a field experiment which would help to do a proper and deep analysis. During the interviews, farmers who adopted push pull were asked whether they were able to identify the number of maize plants infected by stem borer moths as I wanted to collect this information. Only one farmer was able to respond to the question, though he was not sure about the exact growing season it was related to. He recalled that within the measurement of the two plots, 15mx10m each, four maize plants were found containing stem borer larvae in the push pull plot and 13 maize plants were infected in the control plot. Therefore, maize stem borer control was better in push pull system but, this information would have been recorded differently in order to draw general conclusions based on general and accurate data.

4.2. Benefits and limitations of push pull technology

The push pull technology is one among many agroecological practices: composting, mulching, natural bio-pesticides and intercropping systems. These practices improve crop productivity, environmental protection and strengthen farming system resilience (FAO, 2014). Three main themes that emerged as benefits from this work have implications for the future of push pull technology in the study area. These themes are stem borer control, improved quality and quantity of maize produce, and improved soil fertility.

The control of maize stem borer through push pull mixed cropping system improves both the quality and quantity of maize produce. According to the land use consolidation program, maize is mainly grown in Gatsibo District where the study was conducted. It is already an opportunity for farmers to work on the quality of the maize harvest by expanding push pull technology because they also grow maize as a monocrop, the same as other farmers who are not part of the project. The quality of maize produce is very important to determine the market value of this crop. For example, the Bakhresa Grain Milling (Rwanda) Ltd. Azam Bakhresa Group operating in Kigali with value addition of maize and wheat might be a local potential market. More than half of maize used in this company is currently imported from other countries especially because the local production is not of sufficiently good standards to be accepted at Azam industry. In this case, push pull technology would help farmers to improve the quality of their maize produce to meet the Azam standards. Therefore, farmers can sell their maize harvest under contract with Azam industry. And, this can be well structured if farmers who adopt push pull technology find their own spot at the market as an agriculture cooperative. Consequently, push pull technology can potentially contribute towards better household income and livelihoods improvement in general. In addition, push pull technology is preventive technique of negative environmental effects of conventional practices i.e. the use of pesticides and synthetic fertilizers (Hochedez & Le Gall, 2016. p 2). It is common for farmers to sell their maize production to traditional traders who visit farmers in their homes to buy the production at a very cheap price and then later sell it back to them at double or triple price. The adoption of push pull technology and a well- structured selling can clearly strengthen the value chain of maize and farmers livelihoods status. This structure is needed for farmers to distinguish the quality and determine the price of maize produced in push pull system compared to the maize produce grown as a sole crop. Farmers mentioned another important benefit which was the capacity of the push pull mixed cropping system to increase soil fertility. Push pull mixed cropping enhances nitrogen fixation in the soil due to desmodium legume which is intercropped with maize. Apart from soil fertility improvement, push pull technology is beneficial in reducing pest populations in comparison with conventional fertilizations in monoculture systems (Altieri & Nicholls, 2003). In addition to this, another important benefit of push pull technology is the control of a special weed known as striga (*Striga Hermonthica*).

The striga suppression by desmodium legume is performed through the allelopathic process evolved from the nitrogen availability in the soil body (Khan *et al*., 2002; Tsanuo *et al*., 2003 in Midega *et al.*, 2017, p. 100). This allelopathic effect includes a variety of root exudates released by desmodium, one group of them are responsible to stimulate the suicidal germination of striga weed and the other group of exudates restrain the radical growth (Tsanuo *et al*., 2003; Hooper *et al*., 2009, 2010, in Midega *et al.*, 2017, p. 100). The chemical processes protected maize plants against the nutrient and water sucking by striga root system which would negatively affect the maize yield.

In the previous section, farmers appreciated push pull technology for its potential to help them in reducing by half the quantity of synthetic fertilizers; some apply compost with small quantities of chemical fertilizers, others just use compost and/or animal manure. In fact, the reduction of synthetic fertilizers implies less investment cost and saving of a given amount of money which was used to buy fertilizers. From this fact, push pull adoption provides both short and long term benefits. First, there will be a small budget saving from the early stage of push pull technology. Secondly, like any other cereal-grain legume cropping systems, push pull technology provides environmental benefits such as the conservation of biodiversity and soil health improvement due less chemical fertilization (Stagnari *et al.*, 2017).

The maize yield in the different growing seasons assessed showed the effect of the push pull technology in improving the maize production. Since the introduction of the push pull technology into the maize production system in Rwanda, the research community from the CAVM has undertaken research into the effect of the push pull technology including the soil fertility improvement. The outcomes of ongoing research and the inclusion of RAB in the push pull project implementation is an opportunity to prompt its consideration throughout agricultural policy decision-making (Gatsby Charitable Foundation, 2005). In other words, the effectiveness of the push pull technology can be enhanced and expanded to the maize production sector in general due to the support from recognized institutions in agriculture research.

Looking the limitations side, it was realized that farmers do not normally apply inorganic fertilizers in a correct way. It all depends on the purchasing power of the individual household to buy fertilizers. The adoption of the push pull technology can remediate to this problem and help farmers with the lowest purchasing power and all others to have a sustainable source of nitrogen-based nutrients which is not dependent on the economic status of the household. Among the challenges raised by participants, there was a problem of labor and time allocated to start a push pull plot. It might not be a problem compared to the mentioned benefits and the reduced activity in farm preparation once the plot is established. However, the cutback of desmodium, the harvesting frequency and the cutting height can create the time and labor issues (Mwangi *et al.*, 2004).

Furthermore, there are no typical examples in the prior research findings where time and labor have been predominant limiting factors of push pull technology. For the most part, farmers' understanding and commitment matter to acknowledge the pattern to invest their time and labor in push pull technology installation. It was mentioned that about 20% of farmers combine farming activities with animals (see section 3.1.2), this may not be in accordance with the intention behind the design of the push pull technology, which produce quality fodder for animals.

4.3. Allocation of grasses (desmodium, brachiaria and Napier grass)

The allocation of desmodium, brachiaria or Napier grass was defined based on whether or not the household owns animals (cows, goats, pigs). Farmers who own domestic animals use desmodium and the contouring grass for fodder. The implementing project predicted the livestock distribution to anticipate the grass/fodder allocation among smallholders. All adopters installed a permanent compost container where they collected kitchen residues, grasses, crop residues and animal manure for compost preparation.

In the region, farmers with relatively large pieces of land grow banana and coffee. For this reason, they can allocate desmodium biomass for mulching purposes. Farmers (not necessarily in the programme) can get interested in the push pull technology targeting the desmodium which can be grown in coffee and banana plantations as a fertilizing plant. Alternatively, it is possible that an increase of using desmodium may help to solve the problem related to seeds quality and availability (see section 3.2.3) as the supply of cuttings can be increased. The push pull technology fits in with the existing home grown solutions to improve smallholder livelihoods such as that of "Girinka Munyarwanda" consisting of one cow per poor family. It was initiated by the President to assist poor families in reducing poverty and improving livelihoods through cattle farming (Rwanda Governance Board, 2016). However, a number of households failed to take care of the cow they received due to a lack of space to grow enough fodder; they had to give back the cow. The push pull technology, which produces quality fodder, would strengthen the "Girinka Munyarwanda" program and help it to reach its main objectives.

4.4. Seed availability and crop rotation

The availability of desmodium seed (in quality and quantity) has been considered as one of the limitations, but I chose to discuss it separately and relate it to the local conditions as well as possible solutions in the study area. Farmers in Kenya were aware of the importance of companion grasses to improve soil fertility in push pull mixed cropping system. However, the stunted growth of green leaf desmodium variety right through the establishment period, and the high cost of seeds were the limiting factors to the adoption of this technology (Muyekho *et al.,* 2003). Apart from the costs of desmodium seeds, their production was subjected to different factors such as planting time, light, and rainfall rate (Hare *et al.*, 2007). Roder *et al.* (2002) mentioned the challenge with desmodium seed production and availability to farmers in Bhutan. However, there is no much of information available in the literature regarding seed production techniques and environmental factors influencing seed yield quantity and quality. Different varieties of desmodium can give different germination responses as the green leaf variety did not well germinated as the silver leaf variety in the study area.

In the context of this study, the low germination rate of green leaf desmodium was observed in the plots and was mentioned by the majority of the participants. Subsequently, the same phenomenon as in Kenya happened in the study area; therefore achieving project success which is embedded in the success of push pull technology, can be problematic. On the other hand, the solution to this problem is clear. The silver leaf desmodium variety is adapted to the region, farmers found that silver leaf could be multiplied through vegetative propagation and they preferred it to the green leaf variety. Thus, it is the project's task to adopt the right assistance model and accompany farmers in their problem-solving process (Robert, Alban & Bergez, 2016). The budget which was allocated to buy seeds of desmodium and brachiaria can be reallocated to multiplication of silver leaf cuttings at the level of the model farmer's household. The participation of farmers in an agricultural project like the push pull technology strengthens their understanding and promotes their sense of project ownership which leads to its sustainability even after the project funding has come to an end (Aref, 2011). Another concern regarding the effectiveness of the push pull technology in the study area is related to the maize seeds provided by the Food for the Hungry/Rwanda.

Traditional seed saving and sharing would help to stabilize and secure the push pull technology, because the development of community seed banks plays a crucial role in climate change adaptation and sustainability of the system (Vernooy *et al.*, 2016). The availability of desmodium cuttings and maize seeds in the community can therefore help to increase the practicability of the push pull technology and enhance all its benefits (natural, physical and socio-economic). The use of adapted desmodium variety and the development of community seed saving throughout the project implementation are durable coping strategies to enhance the push pull technology effectiveness and sustainability in the study region. The green leaf desmodium can be damaged by pests like fungal disease (*anthracnose*) and the viral disease known as *little leaf* (Lenne & Stanton, 1990). According to Lenne & Stanton (1990), the green leaf desmodium variety grows better in a fertile soil, and normally has a slow motion of germination than other tropical legumes species. Apparently the green leaf variety of desmodium did not adapt to the local conditions. By contrast, the silver leaf variety was preferred by farmers as it could germinate and cover the soil with a huge amount of biomass which can be used in many ways.

The crop rotation within the push pull system remains a topic to explore. There are no proper crop rotation systems in the traditional farming system due to land scarcity and very low average land sizes. Generally, cereals (maize, sorghum) and legumes (beans, soya) alternate season after season. The possibility to grow beans or other legume crops after a farmer has harvested maize in a farm surrounded by Napier grass or brachiaria was not discussed in the literature; and farmers stressed it as a limitation during the interviews. This can result in having a negative implication for farmers' perceptions of the technology and its further adoption. However, the success of the push pull technology has been observed in Khan *et al.,* (2010), Midega *et al.,* (2015), Kassie et al., (2018), Midega *et al.,* (2018) and many other different studies conducted in sub-Saharan Africa countries. In all these previous research papers, crop rotation was not discussed as the main problem to the expansion of the push pull technology. Yet, perennials (desmodium, Napier grass and brachiaria) do not favor crop rotation, but if farmers do not have enough land and they need to diversify nutrient sources, it can be hard for them to go for the expansion of push pull technology.

4.5. Famer knowledge and cultural acceptability of push pull technology.

The farmer's knowledge is the result of traditional knowledge in farming activities, the farmers' curiosity, innovations and efforts within the farming system (Heryanto *et al.,* 2018). The adoption of the push pull technology was positively influenced by the education level of farmers. More educated farmers were more likely to adopt the technology which after all is quite knowledge intensive. The promotion of farmers' knowledge would be a powerful tool to speed up the transfer the adoption and/or the transition to new practices. The knowledge and skills acquired i.e. from trainings, is shared among farmers either orally or in practice (Hoffman *et al.,* 2006).

Farmers admitted that knowledge is the key that is why they appreciated trainings and field days to scale up their knowledge level. Having model farmers with a certain level of education is very important to properly communicate knowledge within their groups. The appreciation and performance of one model farmer, who holds a high school diploma in veterinary services, implied the need to have skilled farmers to spread the push pull technology. All respondents admitted to learn different things from that exemplary farmer whether they belong to his group or not.

The push pull technology is relatively similar to traditional African intercropping practices of maize with beans, sorghum with sweet potatoes, cassava with ground nuts and others. It has therefore been easy to secure the community's acceptance. Through the promotion of community leadership by model farmers, it is anticipated that the sustainability of the push pull technology will be reinforced. In order to further expand the adoption of push pull technology, farmers (adopters) suggested the use of silver leaf as it propagates more easily than the green leaf variety. From this experience, farmers developed new knowledge and they were able to decide and make right choices for the best application and profitability of the push pull technology. Therefore, farmers get new skills and experiences throughout the implementation of the push pull technology. The source of agriculture information and the tools at the farmers' service play a big role in the development of the farmer's knowledge. And, the farmer knowledge development facilitates the workflow in agriculture implementation for example the adoption and expansion of push pull technology.

4.6. Redesigning maize food system with agroecology

Agroecology is a process of redesigning food systems, from the production to the consumption, with the goal of attaining ecological, economic, and social sustainability (Gliessman, 2016). Through participatory and transdisciplinary research, agroecology combines science, practices and movements centered to social change. In his agroecology textbook of 2015, Gliessman proposed an analytical framework on five levels of conversion of food systems where every level of conversion is characterized by a specific goal and related elements of agroecology as shown in (Table 2).

Table 2: Five levels of food system transformation.

	Levels of transition		**Elements of Agroecology**	
Incremental	1	Increase efficiency of inorganic inputs.	Agro-ecosystem level	Efficiency
	2	Replacement the alternative practices and inputs for the conventional practices		Recycling and Regulations
	3	Restructure the agroecosystem for that it functions based on the latest ecological processes.		Diversification, synergies and system resilience
Transformational	4	Re-establish the relationship between producers and consumers, start alternative food networks	Food system level	Generate the knowledge, culture and food transition, circular economy
	5	Rebuild the extended food system so that it is sustainable, fair and equitable for all.		Social value & Responsible Governance

The first three levels show the processes that farmers can control on their farms for conversion from conventional practices. The fourth and fifth levels go beyond the farm level and take into account the socio-economic dimensions such as food markets and responsible governance. Going through all the five levels, can gradually move the entire food system to the global transformation of the food system. The standing point of the push pull technology within the five levels of Gliessman, defines how far it is effective and sustainable. The push pull technology fits in with the agroecosystem level (incremental). It covers three first levels of conversion, including six elements of agroecology as defined by FAO: efficiency, recycling, regulation, diversity, synergies and resilience. According to Gliessman (2015), if a system has reached the third level of conversion it is therefore, in line with the principles of agroecology on the farm level. Therefore, it is reasonable to assess the push pull technology within Gliessman's framework explaining five levels of conversion.

After all, the development of the agricultural system is highly influenced by the existing political system, the responsible governance and the economic policy existing in the country (Hoeffler, 2011). However, the responsible governance is possible when the society understands the environmental problems and how the decisions made currently have an important impact on future generations.

5. Conclusions

The agricultural sector in general and maize production in particular, has been subjected to pest and soil impoverishment problems that have led to low productivity. Agriculture reforms like the Land use consolidation and CIP program were used to find relevant solutions. The adoption of the push pull technology was introduced to combat the maize stem borer, a key-pest causing major losses in maize harvest. This pest used to damage maize crop in different growing seasons, but in the early 2014 the damage was devastating and the problem was in almost all corners of the country.

The Food for the Hungry/Rwanda delivered training, maize and desmodium seeds to assist farmers in the Gatsibo District through the adoption process of the push pull technology. Farmers in the studyarea, both adopters and non-adopters, appreciated the technology for its effectiveness to control maize stem borer as well as to increase maize yields as fodder to animals. However, farmers also pointed out the limiting factors of the push pull technology, such as the seed quality of desmodium, seed availability of brachiaria. The market situation also is a big problem for farmers because the market is saturated with maize at the harvest time. The land shortage, limited income source and the need for diversification were also issues raised by farmers as constraints to expand push pull technology. From their experience, farmers noticed that availability and quality of desmodium seed would not need to be a limitation for the continuous adoption of the push pull technology. The silver leaf variety has been the farmers' preference as it multiplies by vegetative propagation and has more biomass quantity than the green leaf variety. As few farmers own livestock, Food for the Hungry/Rwanda included the animal distribution component for the good allocation of fodder. Due to the complexity of the situation, the contribution of the push pull technology to the household income and food security nutrition was not easy to identify. The expansion of an agriculture practice, such as the push pull technology requires a close collaboration and understanding between the different stakeholders involved in this sector (Francis *et al.*, 2013).

RAB, ICIPE and researchers from CAVM are expected to contribute to find solutions to the challenging aspects of the push pull technology, especially the crop rotation possibilities and the structure of the maize value chain. It is very important for Food for the Hungry/Rwanda, as an implementing project, to produce training modules to facilitate knowledge and information sharing during the project intervention period as well as after the project funding has ended. Food for the Hungry/Rwanda organization has a pre-defined logical framework to achieve the objectives and results. The combination of push pull technology with the small livestock is a strong point for the allocation of fodder from push pull plots, but also for the diversification of income source and the livelihood improvement in general.

For this technology to expand and move to the higher levels of the Gliessman's framework outlined in the previous section (4.5), a consolidated effort from the government including fuller collaboration between all engaged stakeholders is required. In fact, the research question about the strategy to overcome any challenges could not have an exact response. Thus, the consideration of the push pull technology by all actors in the maize production sector , the commitment to address the existing limitations, and the understanding of the benefits attached to it will increase its effectiveness as well as further adoption by maize growers.

6. Personal reflections

The intervention of Food for the Hungry/Rwanda is very important in the region. Apart from the push pull technology, the organization delivers useful tool kits for farmers' empowerment and their knowledge strengthens in general. However, only the farmers themselves can assure durability and longevity of the push pull technology and other agroecological practices following the project's intervention. The inclusion of sector and district agronomists in the training programme offered by Food for the Hungry/Rwanda can ensure the future of this technology. After they are involved in the program, agronomists can play an important role as they are one of the best sources of agriculture information (see section 3.2.1). The implementing project has already prepared a training series for farmers; therefore, it is also important to equip farmers' groups with training modules to help them in information and knowledge sharing even after the project funding has come to an end.

It is all too common that the findings from research projects never get beyond research reports on book shelves or published papers that end users (farmers) do not access. I think there is very interesting agricultural expertise in Rwanda, but the decision making process and governance structure do not provide the platform to take the lead and express what is right for the betterment of today's farmers and for future generations. In such a situation, the food system i.e. maize production is unlikely to attain the higher levels on Gliessman's framework (see section 4.2). Therefore, all stakeholders in the agricultural sector should collaborate and engage together to find solutions to the existing problems in a long term perspective. For example, the crop rotation can be subjected to research as it is clear that there is a research gap about rotation of crops in the push pull system; research institutions and the College of Agriculture are likely to intervene on this specific topic. The MINAGRI should support the push pull system as it may be a long lasting solution to maize yield losses, soil fertility problems and its complementarity with small livestock is very useful for farmers' livelihoods.

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Appendix

l. List of farmers with push pull technology

No	Names	Occupation	Cell	Village
1	Mpumuje Jean Claude	Model farmer	Mayange	Nyarubuye
2	Gahigi Leonidas	Disciple farmer	Mayange	Kabuye
3	Munyaneza Zephilin	Model farmer	Nyagitabire	Kuwingeri
4	Musabyemariya Mariam	Model farmer	Nyagitabire	Nyamikamba
5	Muhayimana Daphrosa	Model farmer	Gitinda	Isangano
6	Shyirakera Ildephonse	Model farmer	Mayange	Rweza
7	Niyibizi Sylveria	Model farmer	Nyagitabire	Kibatsi
8	Kamana Silver	Disciple farmer	Nyagitabire	Nyamikamba
9	Mpirimba Innocent	Disciple farmer	Nyagitabire	Nyamikamba
10	Muganga Onesphore	Disciple farmer	Gitinda	Isangano
11	Nimurere Lodie	Disciple farmer	Mayange	Mpangare 1
12	Bugenimana Jean	Disciple farmer	Gitinda	Gatungo
13	Mukarusagara Marie Rose	Disciple farmer	Mayange	Rweza
14	Uwizeyimana Pascasie	Ababerarugo	Gitinda	Isangano
15	Bizimana JMV	COCUBANYA	Mayange	Kabuye

2. List of farmers without push pull technology

No	Names	Cell	Village
1	Ngarukiye Emmanuel	Nyagitabire	Nyamikamba
2	Nsabimana Evariste	Nyagitabire	Nyamikamba
3	Nyirahabimana Esperance	Nyagitabire	Nyamikamba
4	Nkundabagenzi Marc	Nyagitabire	Nyamikamba
5	Habaguhirwa Vénutse	Nyagitabire	Nyamikamba
6	Ntawigenera Laurent	Nyagitabire	Nyamikamba
7	Nyiramisago	Nyagitabire	Nyamikamba
8	Nsanzumuremyi Kizito	Nyagitabire	Nyamikamba
9	Nyirahategekimana Jeanine	Nyagitabire	Nyamikamba
10	Rekayo Thacien	Nyagitabire	Byimana
11	Mukagahutu Béatha	Nyagitabire	Nyamikamba
12	Mukazitoni Valentine	Nyagitabire	Nyamikamba
13	Ntabanganyimana Diogene	Nyagitabire	Nyamikamba
14	Mukandayisenga	Nyagitabire	Nyamikamba
15	Ndabarinze Anastase	Nyagitabire	Nyamikamba

The interview guide

1. General information

Name Date Location

a. Age

b. What is the size of your farm?

c. What is your role in the farm?

Owner Other (specify)

d. How long have you been involved in farming?

e. Besides you, who are the people working in the farm enterprise? Spouse

f. Hired labor (temporary) Hired labor (full time) Children Other (specify)

g. Is the farming the sole source of family income? Yes If not, what else?

h. What are the main crops grown in the farm?

i. Which crops and how much of the harvest are used for home consumption?

Estimation (percentage, half, quarter, and others).

2. Source of agricultural information and farm knowledge

a. Have you ever gone to school?

Primary High school University

b.Where do you take the knowledge you use in you farming activities?

Parents/grand-parents

Neighbors / other farmers

Formal training sessions

Radio programme

Advisory services

Others (specify)

3. Inputs (seeds, fertilizers, others)

a. What are the main inputs you purchase on a growing season basis?

b. Do you keep records in your farming activities? If yes please elaborate.

4. Push pull technology

a. Have ever heard about push pull technology?

b.When was that and where did you take the information? c. Do you have push pull technology in your farming system?

If yes, please describe.

If no, would you like to have it in your farm? Why?

d. Do you see any type of benefits of using push pull technology to grow maize? Please elaborate.

e. How do you compare your maize produce before using push pull technology and now you use it? (For those who use push pull technology).

f. Are they limitations in using push pull technology? Please elaborate.

g. Do you have any suggestions about those limitations? Please elaborate and specify to whom the message goes.